(54) DISPERSION-SHIFTED OPTICAL FIBER

(57)   The present invention relates to a dispersion-shifted optical fiber suitable for an optical transmission line having an optical fiber amplifier with a wider amplification band. In particular, the dispersion-shifted optical fiber according to the present invention has a zero-dispersion wavelength of 1610 nm or more but 1670 nm or less, and a cutoff wavelength of 1.1 μm or more at a length of 2 m in order to suppress the bending loss to a practically permissible range, and has, with respect to light having a wavelength of 1550 nm, an effective area of 50 μm² or more and a dispersion slope of 0.15 ps/nm²/km or less in order to suppress the occurrence of nonlinear phenomena.

Fig.2
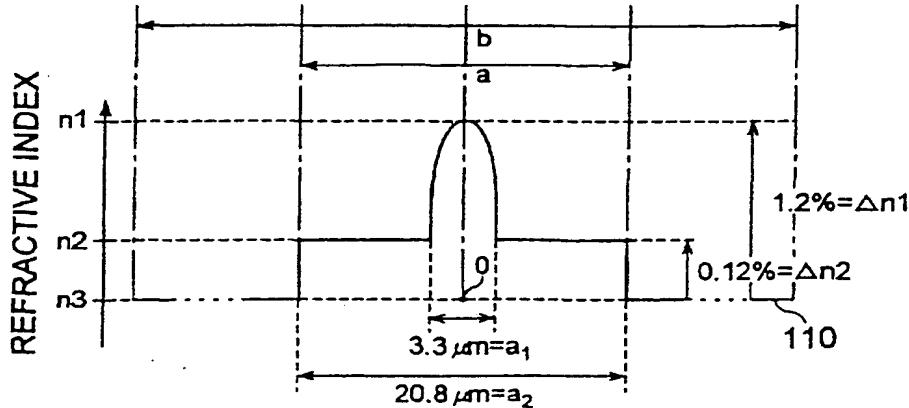
Description

Technical Field

[0001] The present invention relates to a single-mode optical fiber usable as a transmission line in optical communications and the like; and, in particular, to a dispersion-shifted optical fiber suitable for wavelength division multiplexing (WDM) transmission.

Background Art

[0002] In general, a WDM transmission system using optical fiber networks is a system enabling long-distance, large-capacity optical data communications, and is constituted by a transmitter/receiver for transmitting and receiving WDM signals of a plurality of wavelengths (light signals), an optical amplifier such as an optical fiber amplifier for amplifying the WDM signals, an optical fiber which is a transmission medium, and the like. In such a WDM transmission system, the wavelength band that can optically be amplified in the optical amplifier is from 1530 nm to 1560 nm, whereas the low-loss wavelength band in the optical fiber is from 1400 nm to 1700 nm. As a consequence, the wavelength band utilizable as the WDM signals in the conventional WDM transmission system has substantially been limited to a width of about 30 nm from 1530 nm to 1560 nm.

[0003] The amplification of WDM signals by the optical amplifier increases the optical power of each light signal in the optical fiber acting as the transmission medium, thereby causing nonlinear phenomena such as four-wave mixing, self phase modulation, modulation instability, and the like. In particular, the four-wave mixing causes power variations among the individual signal components, whereas the self phase modulation distorts the pulse waveform of each light signal upon an interaction with the chromatic aberration of the optical fiber (hereinafter referred to as dispersion), whereby the occurrence of such nonlinear phenomena limits the normal transmission of light signal.

Disclosure of the Invention

[0004] The inventors have studied the case where a conventional dispersion-shifted optical fiber is employed in a WDM transmission system and, as a result, have found problems as follows.

[0005] Namely, for effectively suppressing the four-wave mixing, it is preferred that the wavelength of each light signal be different from the zero-dispersion wavelength of the optical fiber. For effectively suppressing the self phase modulation, on the other hand, it is preferred that the absolute value of dispersion value of the optical fiber with respect to each light signal be not so large.

[0006] When the four-wave mixing and the self phase modulation are compared with each other, the distortion in pulse waveform of each light signal caused by the self phase modulation can be alleviated to a certain extent by a dispersion-compensating technique in which a dispersion-compensating optical fiber (having a dispersion characteristic with a polarity opposite to that of the dispersion value of the optical fiber acting as the transmission medium) is inserted in the optical transmission line through which each light signal propagates, so that the dispersion value of the optical transmission line as a whole becomes nearly zero. By contrast, no technique has been known for compensating for the crosstalk between individual light signals caused by the four-wave mixing. Therefore, as compared with the self phase modulation, it is more important to suppress the four-wave mixing.

[0007] In view of the increase in noise components caused by the modulation instability, on the other hand, it is preferred that the zero-dispersion wavelength be set on the longer wavelength side from the wavelength band of each light signal. Further, letting N2 be the nonlinear refractive index of the optical fiber, A_{eff} be the effective area thereof, P be the power of light the propagating therethrough, and L_{eff} be the effective length of the optical fiber, the amount of occurrence of nonlinear phenomena in the optical fiber is given by the following expression (1):

$$N2 \cdot P \cdot L_{eff} / A_{eff} . \qquad (1)$$

[0008] Among these parameters, the nonlinear refractive index N2 is determined by the material of the optical fiber, whereby it is necessary for the effective area A_{eff} of the optical fiber to increase in order to reduce the amount of occurrence of nonlinear phenomena.

[0009] Here, as shown in Japanese Patent Application Laid-Open No. HEI 8-248251 (EP 0 724 171 A2), the above-mentioned effective area A_{eff} is given by the following expression (2):

$$A_{eff} = 2\pi \left(\int_0^\infty E^2 r dr \right)^2 / \left(\int_0^\infty E^4 r dr \right) \qquad (2)$$

where E is the electric field accompanying the propagating light, and r is the radial distance from the center of the core region.

[0010] In the conventional WDM transmission system, as a result of the foregoing studies, it is preferred that the zero-dispersion wavelength of the optical fiber be restricted to the range of 1560 nm to 1600 nm, and that its effective area A_{eff} be 50 μm^2 or more. Further, for suppressing the increase in loss upon cabling the optical fiber, it is preferred that its bending loss be smaller, whereby its cutoff wavelength must be set to an appropriate value.

[0011] In the conventional WDM transmission sys-

tem, the wavelength distance between the individual light signals included in the WDM signals is about 1 nm, whereby the actual multiplicity has been limited to about 30 waves. For enhancing the transmission capacity, however, it is desirable that the wavelength multiplicity be increased. In this case, while a method of narrowing the wavelength distance and a method of enlarging the wavelength bandwidth can be considered, the latter is preferred in view of the above-mentioned suppression of four-wave mixing.

[0012]   On the other hand, the amplification wavelength band of the optical fiber amplifier has been expanding along with the advance in technology, thereby making it possible to amplify the WDM signals in a wider wavelength band of 1530 nm to 1610 nm (see, for example, A. Mori, et al., "1.5 μm Broadband Amplification by Tellurite-Band EDFAs," OFC '97, PD1). In contrast, the zero-dispersion wavelength of the conventional dispersion-shifted optical fiber lies within the range of 1560 nm to 1600 nm as mentioned above. Therefore, in a WDM transmission system employing the optical fiber amplifier having thus expanded amplification wavelength band and the conventional dispersion-shifted optical fiber, there is a possibility that the zero-dispersion wavelength of the conventional dispersion-shifted optical fiber may lie within the wavelength band that can be amplified by the optical fiber amplifier (the signal wavelength band of WDM signals), so that the four-wave mixing may occur strongly, whereby the WDM signals may not be transmitted normally.

[0013]   In order to overcome the problems such as those mentioned above, it is an object of the present invention to provide a dispersion-shifted optical fiber suitable for an optical transmission line in which an optical fiber amplifier having an expanded amplification band is installed.

[0014]   The dispersion-shifted optical fiber according to the present invention is a single-mode optical fiber comprising a core region extending along a predetermined axis, and a cladding region provided on the outer periphery of the core region; wherein a zero-dispersion wavelength is set within a range of 1610 nm or more but 1670 nm or less so that the optical fiber is employable in a WDM transmission system including an optical amplifier having an expanded amplification wavelength band. Also, the dispersion-shifted optical fiber according to the present invention has a cutoff wavelength of 1.1 μm or more at a length of 2 m and has, with respect to light having a wavelength of 1550 nm, which is light in a signal wavelength band, an effective area of 50 μm^2 or more, preferably 70 μm^2 or more, and a dispersion slope of 0.15 ps/nm^2/km or less.

[0015]   Since the dispersion-shifted optical fiber according to the present invention has an effective area of 50 μm^2 or more, preferably 70 μm^2 or more, it can suppress nonlinear phenomena by the same extent as that of the conventional dispersion-shifted optical fiber or more. While the absolute value of dispersion value in

a typical optical fiber having a zero-dispersion wavelength near 1.3 μm becomes about 20 ps/nm/km when employed in WDM transmission in a 1.5-μm wavelength band, a certain degree of transmission quality can be guaranteed by utilization of a dispersion compensating technique such as that mentioned above. Therefore, the dispersion-shifted optical fiber according to the present invention has a dispersion slope of 0.15 ps/nm^2/km or less with respect to light a wavelength of 1550 nm so that the absolute value of dispersion value becomes 20 ps/nm/km or less. Further, in accordance with the specification of Bellcore, it is necessary that the bending loss upon bending at a diameter of 32 mm be 0.5 dB/turn or less. Therefore, the cutoff wavelength at a reference length of 2 m (measured by a method defined by ITU international standard) in the dispersion-shifted optical fiber according to the present invention is 1.1 μm or more so that the bending loss at a diameter of 32 mm is 0.5 dB/turn or less. Here, the dispersion slope refers to the gradient of a graph indicating the wavelength dependence of dispersion value (see, for example, Fig. 5A).

[0016]   This dispersion-shifted optical fiber is employable in a WDM transmission system together with an optical amplifier such as an optical fiber amplifier whose amplification wavelength band is expanded, for example, to the range of 1530 nm to 1610 nm. Namely, even in the case where the individual light signals included in the wavelength band of 1530 nm to 1610 nm that can be amplified by the optical fiber amplifier propagate through the dispersion-shifted optical fiber, the occurrence of nonlinear phenomena such as four-wave mixing, self phase modulation, and the like is suppressed. Also, since the dispersion-shifted optical fiber has an excellent bending characteristic, it can realize high-quality optical transmission.

[0017]   For yielding various characteristics such as those mentioned above, the dispersion-shifted optical fiber according to the present invention can be realized by various refractive index profiles.

[0018]   For example, a desirable refractive index profile can be realized when the above-mentioned core region is constituted by a center core having a predetermined refractive index and an outer core provided on the outer periphery of the center core and having a refractive index lower than that of the center core. In this configuration, the maximum value of relative refractive index difference of the center core with respect to a reference area in the cladding region is preferably 0.9% or more in view of its relationship with the zero dispersion wavelength.

[0019]   Also, a desirable refractive index profile can be realized when the above-mentioned core region is constituted by a center core having a predetermined refractive index; an intermediate core provided on the outer periphery of the center core and having a refractive index lower than that of the center core; and, an outer core provided on the outer periphery of the inter-

mediate core and having a refractive index higher than that of the intermediate core. In this configuration, the maximum value of relative refractive index difference of the center core with respect to the reference area in the cladding region is preferably 0.6% or more in view of its relationship with the zero dispersion wavelength.

[0020]   Further, a desirable refractive index profile yielding the above-mentioned various characteristics can be realized when the above-mentioned core region is constituted by a center core having a predetermined refractive index and an outer core provided on the outer periphery of the center core and having a refractive index higher than that of the center core. In this configuration, the maximum value of relative refractive index difference of the outer core with respect to the reference area in the cladding region is preferably 0.8% or more in view of its relationship with the zero dispersion wavelength.

[0021]   Here, the above-mentioned refractive index profile is represented by the relative refractive index difference Δn_i given by the following expression (3):

$$\Delta n_i = (n_i \cdot n_{cd})/n_{cd} \qquad (3)$$

where n_{cd} is the refractive index of the reference area (SiO_2) in the cladding region, and n_i is the refractive index of each part i constituting the core region. Hence, the relative refractive index difference Δn_i is represented with reference to the average refractive index n_{cd} of the reference area in the cladding region. In this specification, the relative refractive index difference is expressed in terms of percentage, and regions having a negative refractive index refer to those having a refractive index lower than that of the reference area.

[0022]   Further, in the dispersion-shifted optical fiber according to the present invention, the cladding region can comprise a depressed cladding structure constituted by an inner cladding provided on the outer periphery of the core region, and an outer cladding provided on the outer periphery of the inner cladding and having a refractive index higher than that of the inner cladding. A combination of this depressed cladding structure and any of the core region structures mentioned above can realize a desirable refractive index profile. In the case of the depressed cladding structure, the above-mentioned relative refractive index difference is given while the above-mentioned outer cladding is employed as the reference area.

Brief Description of the Drawings

[0023]

Fig. 1 is a view showing a schematic structure of a cross section of a dispersion-shifted optical fiber according to the present invention;
Fig. 2 is a view showing the refractive index profile in a first embodiment of the dispersion-shifted opti-

cal fiber according to the present invention;
Fig. 3 is a graph showing the relationship between bending loss and cutoff wavelength in the dispersion-shifted optical fiber according to the first embodiment;
Fig. 4 is a graph showing the relationship between the zero-dispersion wavelength and the relative refractive index difference of the center core in the dispersion-shifted optical fiber according to the first embodiment;
Fig. 5A is a graph showing the dispersion characteristic (wavelength dependence) of an optical fiber having a zero-dispersion wavelength near 1.3 μm, whereas Fig. 5B is a graph showing the dispersion characteristic (wavelength dependence) of the dispersion-shifted optical fiber according to the present invention;
Fig. 6 is a view showing the refractive index profile in a second embodiment of the dispersion-shifted optical fiber according to the present invention;
Fig. 7 is a view showing the refractive index profile in a third embodiment of the dispersion-shifted optical fiber according to the present invention;
Fig. 8 is a view showing the refractive index profile in a fourth embodiment of the dispersion-shifted optical fiber according to the present invention;
Fig. 9 is a view showing the refractive index profile in a fifth embodiment of the dispersion-shifted optical fiber according to the present invention;
Fig. 10 is a view showing the refractive index profile in a sixth embodiment of the dispersion-shifted optical fiber according to the present invention;
Fig. 11 is a view showing the refractive index profile in a seventh embodiment of the dispersion-shifted optical fiber according to the present invention;
Fig. 12 is a view showing the refractive index profile in an eighth embodiment of the dispersion-shifted optical fiber according to the present invention;
Fig. 13 is a view showing the refractive index profile in a ninth embodiment of the dispersion-shifted optical fiber according to the present invention; and
Fig. 14 is a table listing various characteristics of the dispersion-shifted optical fibers according to the first to ninth embodiments.

Best Mode for Carrying Out the Invention

[0024]   In the following, individual embodiments of the dispersion-shifted optical fiber according to the present invention will be explained with reference to Figs. 1 to 4, 5A, 5B, and 6 to 14. In the explanation of the drawings, constituents identical to each other will be referred to with numerals or letters identical to each other without repeating their overlapping descriptions.
[0025]   As shown in Fig. 1, a dispersion-shifted optical fiber 100 according to the present invention is a single-mode optical fiber which comprises a core region 100A extending along a predetermined axis and having

an outside diameter a, and a cladding region 100B provided on the outer periphery of the core region 100A and having an outside diameter b, and has a zero-dispersion wavelength set to 1610 nm or more but 1670 nm or less. This dispersion-shifted optical fiber 100 has a cutoff wavelength of 1.1 μm or more at a reference length of 2 m (according to the ITU international standard) and has, with respect to light having a wavelength of 1550 nm, an effective area of 50 μm² or more, preferably 70 μm² or more, and a dispersion slope of 0.15 ps/nm²/km or less. As shown in first to ninth embodiments which will be mentioned later, each of the above-mentioned core region 100A and cladding region 100B can be constituted by a plurality of glass areas having refractive indices different from each other.

[0026]   The zero-dispersion wavelength of the dispersion-shifted optical fiber 100 according to the present invention is set outside the wavelength band of 1530 nm to 1610 nm, in which each light signal can be amplified when an optical fiber amplifier having an expanded amplification wavelength band is employed in a WDM transmission system, and on the longer wavelength band side from this amplification wavelength band. Therefore, the occurrence of four-wave mixing is effectively suppressed. Also, since the upper limit of the zero-dispersion wavelength of the dispersion-shifted optical fiber 100 is 1670 nm, whereas the upper limit of its dispersion slope is 0.15 ps/nm²/km, the absolute value of dispersion of the dispersion-shifted optical fiber 100 can be suppressed to 21 ps/nm/km or less in the amplification wavelength band of the optical fiber, 1530 nm to 1610 nm, because of the reason that will be mentioned later. As a consequence, the interaction between the self phase modulation and the dispersion of the dispersion-shifted optical fiber 100 can sufficiently be lowered by a dispersion-compensating technique. Also, since the effective area is 50 μm² or more, preferably 70 μm² or more, the power density of each light signal propagating through the dispersion-shifted optical fiber 100 is kept low, whereby the occurrence of nonlinear phenomena is suppressed. Further, since the cutoff wavelength at 2 m is 1.1 μm or more, this dispersion-shifted optical fiber has an excellent bending characteristic. Therefore, WDM transmission systems employing the dispersion-shifted optical fiber 100 according to the present invention enable high-quality optical transmissions even when an optical fiber amplifier having an expanded amplification wavelength band is employed therein.

[0027]   Nine embodiments of the dispersion-shifted optical fiber 100 according to the present invention will now be explained. Here, each of the dispersion-shifted optical fibers according to the first and second embodiments has a refractive index profile of a double core structure. Each of the dispersion-shifted optical fibers according to the third to fifth embodiments has a multilayer core structure. Each of the dispersion-shifted optical fibers according to the sixth and seventh

embodiments has a ring core structure. The dispersion-shifted optical fiber according to the eighth embodiment has a refractive index profile in which a depressed cladding structure and a ring core structure are combined together. The dispersion-shifted optical fiber according to the ninth embodiment has a refractive index profile of a double ring core structure.

First Embodiment

[0028]   Fig. 2 is a view showing the refractive index profile of the dispersion-shifted optical fiber according to the first embodiment. This refractive index profile 110 corresponds to the refractive index of each part on a line L passing the center axis O of the dispersion-shifted optical fiber 100 shown in Fig. 1.

[0029]   As with the dispersion-shifted optical fiber 100 shown in Fig. 1, the dispersion-shifted optical fiber according to the first embodiment comprises a core region having an outside diameter a and a cladding region having an outside diameter b. The core region (corresponding to the core region 100A in Fig. 1) has a double core structure constituted by a center core having a maximum refractive index n_1 and an outer core provided so as to surround the outer periphery of the center core and having a refractive index n_2 ($< n_1$). The cladding region (corresponding to the cladding region 100B in Fig. 1), which is provided so as to surround the outer periphery of the core region, has a refractive index n_3 ($< n_2$), whereby the respective refractive indices of the individual regions have the relationship in terms of magnitude of $n_3 < n_2 < n_1$.

[0030]   The outside diameter a_1 of the center core is 3.3 μm, the outside diameter a_2 (equal to the outside diameter a of the core region) of the outer core surrounding the center core is 20.8 μm, and the outside diameter b of the cladding region surrounding the outer core is 125 μm. The relative refractive index difference of each region is given by expression (3) while the cladding region having the refractive index n_3 is employed as the reference area, whereby the maximum value Δn_1 of relative refractive index difference of the center core with respect to the cladding region is +1.2%, and the relative refractive index difference Δn_2 of the outer core with respect to the cladding region is +0.12%.

[0031]   Upon measurement of various characteristics of the dispersion-shifted optical fiber according to the first embodiment, the zero-dispersion wavelength, the cutoff wavelength at a length of 2 m, and the bending loss at a diameter of 32 mm were 1645 nm, 1.46 μm, and 0.01 dB/turn, respectively. Also, with respect to light having a wavelength of 1550 nm, the effective area and the dispersion slope were 56 μm² and 0.13 ps/nm²/km, respectively.

[0032]   Fig. 3 is a graph showing the relationship between the bending loss (dB/turn) at a diameter of 32 mm and the cutoff wavelength (μm) at a length of 2 m in the dispersion-shifted optical fiber according to the

present invention. This graph is the result of measurement in the state where the effective area and zero-dispersion wavelength were set within the ranges of 53 ± 3 μm^2 and 1645 ± 20 nm, respectively, showing the relationship between the cutoff wavelength and bending loss when the cutoff wavelength was successively changed as the shape of refractive index profile shown in Fig. 2 was slightly altered.

[0033]   For example, the bending loss at a diameter of 32 mm is 0.5 dB/turn or less according to the specification proposed by Bellcore. Therefore, in order to satisfy the specification of Bellcore, it is necessary for the cutoff wavelength at a length of 2 m to be 1.1 μm or more as can be seen from Fig. 3. Here, the bending loss is expressed in terms of the value per turn of the transmission loss measured when a plurality of turns of the optical fiber to be measured are wound about a mandrel having a diameter of 32 mm.

[0034]   In general, while the dispersion characteristic of the optical fiber is expressed by the sum of material dispersion and waveguide dispersion (structural dispersion), it has been known that, when the material dispersion is taken into account, the zero-dispersion wavelength shifts toward the longer wavelength side as a greater amount of GeO_2 is included. Therefore, the zero-dispersion wavelength can easily be shifted toward the longer wavelength side if the GeO_2 concentration is made higher in an area with a higher optical power (e.g., the center core in the case of a double core structure or the outer core in the case of a ring core structure), i.e., if the relative refractive index difference of this area with respect to the cladding region (reference area) is made greater. Fig. 4 is a graph showing the relationship between the zero-dispersion wavelength and the relative refractive index difference of the area having the highest refractive index (the center core in the first embodiment) in the dispersion-shifted optical fiber according to the first embodiment. This graph shows the change in zero-dispersion wavelength when the relative refractive index difference Δn_2 of the outer core (refractive index n_2) with respect to the cladding region (refractive index n_3) acting as the reference area (given by expression (3)), and the ratio (a_1/a_2) of the outside diameter a_1 of the center core to the outside diameter a_2 of the outer core in the core region are held constant. However, the outside diameter a_2 of the outer core is changed such that the effective area becomes 56 μm^2.

[0035]   As can also be seen from the graph of Fig. 4, the maximum value Δn_1 of relative refractive index difference of the center core with respect to the cladding region is needed to be 0.9% or more in the first embodiment in order to set the zero-dispersion wavelength to 1610 nm or more.

[0036]   While a typical optical fiber (optical fiber for light signals in the 1.3-μm band) has a zero-dispersion wavelength which is set near 1310 nm, it can also transmit light signals in the 1.5-μm band by utilizing the above-mentioned dispersion-compensating technique.

In this case, while a dispersion of about +17 ps/nm/km occurs with respect to light signals in the 1.5-μm band in this typical optical fiber (see Fig. 5A), there will conversely be no practical problems if the absolute value of dispersion value is suppressed to this level. If this theory is applied to the dispersion-shifted optical fiber according to this embodiment, then it can be seen that, as shown in Fig. 5B, a sufficient transmission quality is secured when the dispersion slope is set to 0.15 ps/nm^2/km or less (about -21 ps/nm/km at the maximum in the signal wavelength band in this embodiment) even in the case where the zero-dispersion wavelength is set on the longer wavelength side from the signal wavelength band.

Second Embodiment

[0037]   Fig. 6 is a view showing the refractive index profile of the dispersion-shifted optical fiber according to the second embodiment. This refractive index profile 120 corresponds to the refractive index of each part on the line L passing the center axis O of the dispersion-shifted optical fiber 100 shown in Fig. 1.

[0038]   As with the dispersion-shifted optical fiber 100 shown in Fig. 1, the dispersion-shifted optical fiber according to the second embodiment comprises a core region having an outside diameter a and a cladding region having an outside diameter b. The core region (corresponding to the core region 100A in Fig. 1) has a double core structure constituted by a center core having a maximum refractive index n_1 and an outer core provided so as to surround the outer periphery of the center core and having a refractive index n_2 $(< n_1)$. The cladding region (corresponding to the cladding region 100B in Fig. 1), which is provided so as to surround the outer periphery of the core region, has a refractive index n_3 $(< n_2)$, whereby the respective refractive indices of the individual regions have the relationship in terms of magnitude of $n_3 < n_2 < n_1$.

[0039]   The outside diameter a_1 of the center core is 2.8 μm, the outside diameter a_2 (equal to the outside diameter a of the core region) of the outer core surrounding the center core is 23.6 μm, and the outside diameter b of the cladding region surrounding the outer core is 125 μm. The relative refractive index difference of each region is given by expression (3) while the cladding region having the refractive index n_3 is employed as the reference area, whereby the maximum value Δn_1 of relative refractive index difference of the center core with respect to the cladding region is +1.4%, and the relative refractive index difference Δn_2 of the outer core with respect to the cladding region is +0.12%.

[0040]   Upon measurement of various characteristics of the dispersion-shifted optical fiber according to the second embodiment, the zero-dispersion wavelength, the cutoff wavelength at a length of 2 m, and the bending loss at a diameter of 32 mm were 1628 nm, 1.59 μm, and 0.12 dB/turn, respectively. Also, with

respect to light having a wavelength of 1550 nm, the effective area and the dispersion slope were 71 μm^2 and 0.14 $ps/nm^2/km$, respectively.

Third Embodiment

[0041] Fig. 7 is a view showing the refractive index profile of the dispersion-shifted optical fiber according to the third embodiment. This refractive index profile 130 corresponds to the refractive index of each part on the line L passing the center axis O of the dispersion-shifted optical fiber 100 shown in Fig. 1.

[0042] As with the dispersion-shifted optical fiber 100 shown in Fig. 1, the dispersion-shifted optical fiber according to the third embodiment comprises a core region having an outside diameter a and a cladding region having an outside diameter b. The core region (corresponding to the core region 100A in Fig. 1) has a multilayer core structure constituted by a center core having a maximum refractive index n_1; an intermediate core provided so as to surround the outer periphery of the center core and having a refractive index n_2 ($< n_1$); and an outer core provided so as to surround the outer periphery of the intermediate core and having a refractive index n_3 ($> n_2$, $< n_1$). The cladding region (corresponding to the cladding region 100B in Fig. 1), which is provided so as to surround the outer periphery of the core region, has a refractive index n_4 ($= n_2$), whereby the respective refractive indices of the individual regions have the relationship in terms of magnitude of $n_2 = n_4 < n_3 < n_1$. It is not always necessary for the refractive index n_2 of the intermediate core and the refractive index n_4 of the cladding region to coincide with each other.

[0043] The outside diameter a_1 of the center core is 4.2 μm, the outside diameter a_2 (equal to the outside diameter a of the core region) of the outer core surrounding the center core is 14.6 μm, the outside diameter a_3 of the intermediate core positioned between the center core and the outer core is 9.9 μm, and the outside diameter b of the cladding region surrounding the outer core is 125 μm. The relative refractive index difference of each region is given by expression (3) while the cladding region having the refractive index n_4 is employed as the reference area, whereby the maximum value Δn_1 of relative refractive index difference of the center core with respect to the cladding region is +1.1%, and the relative refractive index difference Δn_3 of the outer core with respect to the cladding region is +0.26%.

[0044] Upon measurement of various characteristics of the dispersion-shifted optical fiber according to the third embodiment, the zero-dispersion wavelength, the cutoff wavelength at a length of 2 m, and the bending loss at a diameter of 32 mm were 1654 nm, 1.35 μm, and 0.08 dB/turn, respectively. Also, with respect to light having a wavelength of 1550 nm, the effective area and the dispersion slope were 57 μm^2 and 0.15 $ps/nm^2/km$, respectively.

Fourth Embodiment

[0045] Fig. 8 is a view showing the refractive index profile of the dispersion-shifted optical fiber according to the fourth embodiment. This refractive index profile 140 corresponds to the refractive index of each part on the line L passing the center axis O of the dispersion-shifted optical fiber 100 shown in Fig. 1.

[0046] As with the dispersion-shifted optical fiber 100 shown in Fig. 1, the dispersion-shifted optical fiber according to the fourth embodiment comprises a core region having an outside diameter a and a cladding region having an outside diameter b. The core region (corresponding to the core region 100A in Fig. 1) has a multilayer core structure constituted by a center core having a maximum refractive index n_1; an intermediate core provided so as to surround the outer periphery of the center core and having a refractive index n_2 ($< n_1$); and an outer core provided so as to surround the outer periphery of the intermediate core and having a refractive index n_3 ($> n_2$, $< n_1$). The cladding region (corresponding to the cladding region 100B in Fig. 1), which is provided so as to surround the outer periphery of the core region, has a refractive index n_4 ($= n_2$), whereby the respective refractive indices of the individual regions have the relationship in terms of magnitude of $n_2 = n_4 < n_3 < n_1$. It is not always necessary for the refractive index n_2 of the intermediate core and the refractive index n_4 of the cladding region to coincide with each other.

[0047] The outside diameter a_1 of the center core is 3.8 μm, the outside diameter a_2 (equal to the outside diameter a of the core region) of the outer core surrounding the center core is 13.8 μm, the outside diameter a_3 of the intermediate core positioned between the center core and the outer core is 9.7 μm, and the outside diameter b of the cladding region surrounding the outer core is 125 μm. The relative refractive index difference of each region is given by expression (3) while the cladding region having the refractive index n_4 is employed as the reference area, whereby the maximum value Δn_1 of relative refractive index difference of the center core with respect to the cladding region is +1.2%, and the relative refractive index difference Δn_3 of the outer core with respect to the cladding region is +0.34%.

[0048] Upon measurement of various characteristics of the dispersion-shifted optical fiber according to the fourth embodiment, the zero-dispersion wavelength, the cutoff wavelength at a length of 2 m, and the bending loss at a diameter of 32 mm were 1624 nm, 1.45 μm, and 0.13 dB/turn, respectively. Also, with respect to light having a wavelength of 1550 nm, the effective area and the dispersion slope were 71 μm^2 and 0.15 $ps/nm^2/Km$, respectively.

Fifth Embodiment

[0049]   Fig. 9 is a view showing the refractive index profile of the dispersion-shifted optical fiber according to the fifth embodiment. This refractive index profile 150 corresponds to the refractive index of each part on the line L passing the center axis O of the dispersion-shifted optical fiber 100 shown in Fig. 1.

[0050]   As with the dispersion-shifted optical fiber 100 shown in Fig. 1, the dispersion-shifted optical fiber according to the fifth embodiment comprises a core region having an outside diameter a and a cladding region having an outside diameter b. The core region (corresponding to the core region 100A in Fig. 1) has a multilayer core structure constituted by a center core having a maximum refractive index n_1; an intermediate core provided so as to surround the outer periphery of the center core and having a refractive index n_2 ($< n_1$); and an outer core provided so as to surround the outer periphery of the intermediate core and having a refractive index n_3 ($> n_2$, $< n_1$). The cladding region (corresponding to the cladding region 100B in Fig. 1), which is provided so as to surround the outer periphery of the core region, has a refractive index n_4 (= n_2), whereby the respective refractive indices of the individual regions have the relationship in terms of magnitude of $n_2 = n_4 < n_3 < n_1$. It is not always necessary for the refractive index n_2 of the intermediate core and the refractive index n_4 of the cladding region to coincide with each other.

[0051]   The outside diameter a_1 of the center core is 5.9 μm, the outside diameter a_2 (equal to the outside diameter a of the core region) of the outer core surrounding the center core is 21.0 μm, the outside diameter a_3 of the intermediate core positioned between the center core and the outer core is 12.6 μm, and the outside diameter b of the cladding region surrounding the outer core is 125 μm. The relative refractive index difference of each region is given by expression (3) while the cladding region having the refractive index n_4 is employed as the reference area, whereby the maximum value Δn_1 of relative refractive index difference of the center core with respect to the cladding region is +0.8%, and the relative refractive index difference Δn_3 of the outer core with respect to the cladding region is +0.19%.

[0052]   Upon measurement of various characteristics of the dispersion-shifted optical fiber according to the fifth embodiment, the zero-dispersion wavelength, the cutoff wavelength at a length of 2 m, and the bending loss at a diameter of 32 mm were 1653 nm, 1.68 μm, and 0.03 dB/turn, respectively. Also, with respect to light having a wavelength of 1550 nm, the effective area and the dispersion slope were 56 μm² and 0.08 ps/nm²/km, respectively.

Sixth Embodiment

[0053]   Fig. 10 is a view showing the refractive index profile of the dispersion-shifted optical fiber according to the sixth embodiment. This refractive index profile 160 corresponds to the refractive index of each part on the line L passing the center axis O of the dispersion-shifted optical fiber 100 shown in Fig. 1.

[0054]   As with the dispersion-shifted optical fiber 100 shown in Fig. 1, the dispersion-shifted optical fiber according to the sixth embodiment comprises a core region having an outside diameter a and a cladding region having an outside diameter b. The core region (corresponding to the core region 100A in Fig. 1) has a ring core structure constituted by a center core having a refractive index n_1 and an outer core provided so as to surround the outer periphery of the center core and having a refractive index n_2 ($> n_1$). The cladding region (corresponding to the cladding region 100B in Fig. 1), which is provided so as to surround the outer periphery of the core region, has a refractive index n_3 ($> n_1$, $< n_2$), whereby the respective refractive indices of the individual regions have the relationship in terms of magnitude of $n_1 < n_3 < n_2$.

[0055]   The outside diameter a_1 of the center core is 3.4 μm, the outside diameter a_2 (equal to the outside diameter a of the core region) of the outer core surrounding the center core is 5.8 μm, and the outside diameter b of the cladding region surrounding the outer core is 125 μm. The relative refractive index difference of each region is given by expression (3) while the cladding region having the refractive index n_3 is employed as the reference area, whereby the relative refractive index difference Δn_3 of the center core with respect to the cladding region is -0.6%, and the maximum value Δn_4 of relative refractive index difference of the outer core with respect to the cladding region is +1.5%.

[0056]   Upon measurement of various characteristics of the dispersion-shifted optical fiber according to the sixth embodiment, the zero-dispersion wavelength, the cutoff wavelength at a length of 2 m, and the bending loss at a diameter of 32 mm were 1634 nm, 1.58 μm, and 5×10^{-10} dB/turn, respectively. Also, with respect to light having a wavelength of 1550 nm, the effective area and the dispersion slope were 53 μm² and 0.09 ps/nm²/km, respectively.

Seventh Embodiment

[0057]   Fig. 11 is a view showing the refractive index profile of the dispersion-shifted optical fiber according to the seventh embodiment. This refractive index profile 170 corresponds to the refractive index of each part on the line L passing the center axis O of the dispersion-shifted optical fiber 100 shown in Fig. 1.

[0058]   As with the dispersion-shifted optical fiber 100 shown in Fig. 1, the dispersion-shifted optical fiber according to the seventh embodiment comprises a core

region having an outside diameter a and a cladding region having an outside diameter b. The core region (corresponding to the core region 100A in Fig. 1) has a ring core structure constituted by a center core having a refractive index n_1 and an outer core provided so as to surround the outer periphery of the center core and having a refractive index n_2 ($> n_1$). The cladding region (corresponding to the cladding region 100B in Fig. 1), which is provided so as to surround the outer periphery of the core region, has a refractive index n_3 ($> n_1$, $< n_2$), whereby the respective refractive indices of the individual regions have the relationship in terms of magnitude of $n_1 < n_3 < n_2$.

[0059]   The outside diameter a_1 of the center core is 4.4 μm, the outside diameter a_2 (equal to the outside diameter a of the core region) of the outer core surrounding the center core is 6.6 μm, and the outside diameter b of the cladding region surrounding the outer core is 125 μm. The relative refractive index difference of each region is given by expression (3) while the cladding region having the refractive index n_3 is employed as the reference area, whereby the relative refractive index difference Δn_3 of the center core with respect to the cladding region is -0.6%, and the maximum value Δn_4 of relative refractive index difference of the outer core with respect to the cladding region is +1.5%.

[0060]   Upon measurement of various characteristics of the dispersion-shifted optical fiber according to the seventh embodiment, the zero-dispersion wavelength, the cutoff wavelength at a length of 2 m, and the bending loss at a diameter of 32 mm were 1658 nm, 1.60 μm, and 3 × 10^{-5} dB/turn, respectively. Also, with respect to light having a wavelength of 1550 nm, the effective area and the dispersion slope were 73 μm^2 and 0.09 ps/nm^2/km, respectively.

Eighth Embodiment

[0061]   Fig. 12 is a view showing the refractive index profile of the dispersion-shifted optical fiber according to the eighth embodiment. This refractive index profile 180 corresponds to the refractive index of each part on the line L passing the center axis O of the dispersion-shifted optical fiber 100 shown in Fig. 1.

[0062]   As with the dispersion-shifted optical fiber 100 shown in Fig. 1, the dispersion-shifted optical fiber according to the eighth embodiment comprises a core region having an outside diameter a and a cladding region having an outside diameter b. The core region (corresponding to the core region 100A in Fig. 1) has a ring core structure constituted by a center core having a refractive index n_1 and an outer core provided so as to surround the outer periphery of the center core and having a refractive index n_2 ($> n_1$). The cladding region (corresponding to the cladding region 100B in Fig. 1), which is provided so as to surround the outer periphery of the core region, has a depressed cladding structure constituted by an inner cladding provided so as to surround

the outer periphery of the outer core and having a refractive index n_3 ($= n_1$), and an outer cladding provided so as to surround the outer periphery of the inner cladding and having a refractive index n_4 ($> n_3$, $< n_2$). As a consequence, the respective refractive indices of the individual regions have the relationship in terms of magnitude of $n_1 = n_3 < n_4 < n_2$. It is not always necessary for the refractive index n_1 of the center core and the refractive index n_3 of the inner cladding to coincide with each other.

[0063]   The outside diameter a_1 of the center core is 4.6 μm, whereas the outside diameter a_2 (equal to the outside diameter a of the core region) of the outer core surrounding the center core is 7.5 μm. On the other hand, the outside diameter b_1 of the inner cladding surrounding the outer core is 11.2 μm, whereas the outside diameter b of the whole cladding region (equal to the outside diameter of the outer cladding) is 125 μm. The relative refractive index difference of each region is given by expression (3) while the outer cladding having the refractive index n_4 is employed as the reference area, whereby the relative refractive index difference Δn_5 of the center core with respect to the outer cladding is -0.4%, the maximum value Δn_6 of relative refractive index difference of the outer core with respect to the outer cladding region is +1.2%, and the relative refractive index difference Δn_7 of the inner cladding with respect to the outer cladding is -0.4%.

[0064]   Upon measurement of various characteristics of the dispersion-shifted optical fiber according to the eighth embodiment, the zero-dispersion wavelength, the cutoff wavelength at a length of 2 m, and the bending loss at a diameter of 32mm were 1663 nm, 1.52 μm, and 4 × 10^{-4} dB/turn, respectively. Also, with respect to light having a wavelength of 1550 nm, the effective area and the dispersion slope were 70 μm^2 and 0.08 ps/nm^2/km, respectively.

Ninth Embodiment

[0065]   Fig. 13 is a view showing the refractive index profile of the dispersion-shifted optical fiber according to the ninth embodiment. This refractive index profile 190 corresponds to the refractive index of each part on the line L passing the center axis O of the dispersion-shifted optical fiber 100 shown in Fig. 1.

[0066]   As with the dispersion-shifted optical fiber 100 shown in Fig. 1, the dispersion-shifted optical fiber according to the ninth embodiment comprises a core region having an outside diameter a and a cladding region having an outside diameter b. The core region (corresponding to the core region 100A in Fig. 1) has a ring core structure constituted by a center core having a refractive index n_1; a first intermediate core provided so as to surround the outer periphery of the center core and having a refractive index n_2 ($>n_1$), a second intermediate core provided so as to surround the outer periphery of the first intermediate core and having a

refractive index n_3 (= n_1), and an outer core provided so as to surround the outer periphery of the second intermediate core and having a refractive index n_4 (>n_3, <n_2). The cladding region (corresponding to the cladding region 100B in Fig. 1), which is provided so as to surround the outer periphery of the core region, has a refractive index n_5 (> n_3, < n_4). As a consequence, the respective refractive indices of the individual regions have the relationship in terms of magnitude of $n_1 = n_3 < n_5 < n_4 < n_2$. It is not always necessary for the refractive index n_1 of the center core and the refractive index n_3 of the second intermediate core to coincide with each other.

[0067] The outside diameter a_1 of the center core is 5.7 μm, the outside diameter a_2 (equal to the outside diameter a of the core region) of the outer core surrounding the center core is 19.1 μm, the outside diameter a_3 of the first intermediate core provided between the center core and the outer core is 9.6 μm, and the outside diameter a_4 of the second intermediate core provided between the first intermediate core and the outer core is 16.2 μm. On the other hand, the outside diameter b of the cladding surrounding the outer core is 125 μm. The relative refractive index difference of each region is given by expression (3) while the cladding region having the refractive index n_5 is employed as the reference area, whereby the relative refractive index difference Δn_5 of the center core and second intermediate core with respect to the cladding region is -1.0%, the maximum value Δn_6 of relative refractive index difference of the first intermediate core with respect to the cladding region is +0.95%, and the relative refractive index difference Δn_7 of the outer cladding with respect to the cladding region is +0.4%.

[0068] Upon measurement of various characteristics of the dispersion-shifted optical fiber according to the ninth embodiment, the zero-dispersion wavelength, the cutoff wavelength at a length of 2 m, and the bending loss at a diameter of 32 mm were 1625 nm, 1.68 μm, and 4 × 10⁻⁴ dB/turn, respectively. Also, with respect to light having a wavelength of 1550 nm, the effective area and the dispersion slope were 94 μm² and 0.07 ps/nm²/km, respectively.

[0069] Fig. 14 is a table listing various characteristics of the dispersion-shifted optical fibers according to the first to ninth embodiments explained in the foregoing. Each of the dispersion-shifted optical fibers according to these embodiments has a zero-dispersion wavelength of 1610 nm or more but 1670 nm or less, and a cutoff wavelength of 1.1 μm or more at a length of 2 m, and has, with respect to light having a wavelength of 1550 nm, an effective area of 50 μm² or more and a dispersion slope of 0.15 ps/nm²/km or less.

[0070] Therefore, each of the dispersion-shifted optical fibers is employable in WDM transmission systems including an optical fiber amplifier adapted to amplify light signals in a wavelength band of 1530 nm to 1610 nm, and effectively suppresses the occurrence of

nonlinear phenomena such as four-wave mixing, self phase modulation, and the like, thereby realizing high-quality optical transmission. In particular, each of the dispersion-shifted optical fibers according to the second, fourth, and seventh to ninth embodiments has an effective area of 70 μm² or more, thus allowing the light signals propagating through the dispersion-shifted optical fiber to keep the power density at a lower level, thereby being able to further suppress the occurrence of nonlinear phenomena.

[0071] Also, each of the dispersion-shifted optical fibers has an excellent bending characteristic. Here, each of the dispersion-shifted optical fibers according to the fifth and ninth embodiments has a cutoff wavelength longer than the signal wavelength. In view of the fact that the actual transmission distance of light signals is several hundreds to several thousands of kilometers, there are no problems since higher-order modes attenuate.

[0072] Without being restricted to the above-mentioned embodiments, the present invention can be modified in various manners. For instance, each of Figs. 2 and 6 to 13 just shows an example of refractive index profiles, and various other shapes can be employed as the refractive index profile for realizing the dispersion-shifted optical fiber according to the present invention.

Industrial Applicability

[0073] As in the foregoing, the dispersion-shifted optical fiber according to the present invention has a zero-dispersion wavelength of 1610 nm or more but 1670 nm or less, and a cutoff wavelength of 1.1 μm or more at a length of 2 m, and has, with respect to light having a wavelength of 1550 nm, an effective area of 50 μm² or more and a dispersion slope of 0.15 ps/nm²/km or less. Therefore, even in the case where each light signal belonging in the wavelength band of 1530 nm to 1610 nm that can optically be amplified by an optical fiber amplifier having an expanded amplification wavelength band propagates through this dispersion-shifted optical fiber, the occurrence of nonlinear phenomena such as four-wave mixing, self phase modulation, and the like is effectively suppressed. Also, since the dispersion-shifted optical fiber according to the present invention has an excellent bending characteristic, high-performance optical transmission can sufficiently be realized over a wide band.

[0074] In the case where the effective area is 70 μm² or more, the power density of each light signal propagating through the dispersion-shifted optical fiber is kept lower, whereby the occurrence of nonlinear phenomena is further effectively suppressed, and higher-quality optical transmission can be realized.

Claims

1.   A dispersion-shifted optical fiber comprising a core

region extending along a predetermined axis and a cladding region provided on the outer periphery of said core region and having a zero-dispersion wavelength of 1610 nm or more but 1670 nm or less;

said dispersion-shifted optical fiber having:
a cutoff wavelength of 1.1 μm or more at a length of 2 m;
an effective area of 50 μm² or more with respect to light having a wavelength of 1550 nm; and
a dispersion slope of 0.15ps/nm²/km or less with respect to light having a wavelength of 1550 nm.

2. A dispersion-shifted optical fiber according to claim 1, having an effective area of 70 μm² or more.

3. A dispersion-shifted optical fiber according to claim 1, wherein said core region comprises a center core having a predetermined refractive index, and an outer core provided on the outer periphery of said center core and having a lower refractive index than said center core.

4. A dispersion-shifted optical fiber according to claim 3, wherein the maximum value of relative refractive index difference of said center core with respect to a reference area in said cladding region is 0.9% or more.

5. A dispersion-shifted optical fiber according to claim 1, wherein said core region comprises a center core having a predetermined refractive index; an intermediate core provided on the outer periphery of said center core region and having a refractive index lower than that of said center core; and an outer core provided on the outer periphery of said intermediate core and having a higher refractive index than said intermediate core.

6. A dispersion-shifted optical fiber according to claim 5, wherein the maximum value of relative refractive index difference of said center core with respect to a reference area in said cladding region is 0.6% or more.

7. A dispersion-shifted optical fiber according to claim 1, wherein said core region comprises a center core having a predetermined refractive index; and an outer core provided on the outer periphery of said center core and having a higher refractive index than said center core.

8. A dispersion-shifted optical fiber according to claim 7, wherein the maximum value of relative refractive index difference of said outer core with respect to a

reference area in said cladding region is 0.8% or more.

Fig.1

100

100A

0

L

100B

a

b

Fig.2

REFRACTIVE INDEX

b

a

n1

n2

n3

0

$1.2\% = \triangle n1$

$0.12\% = \triangle n2$

110

$3.3 \mu m = a_1$
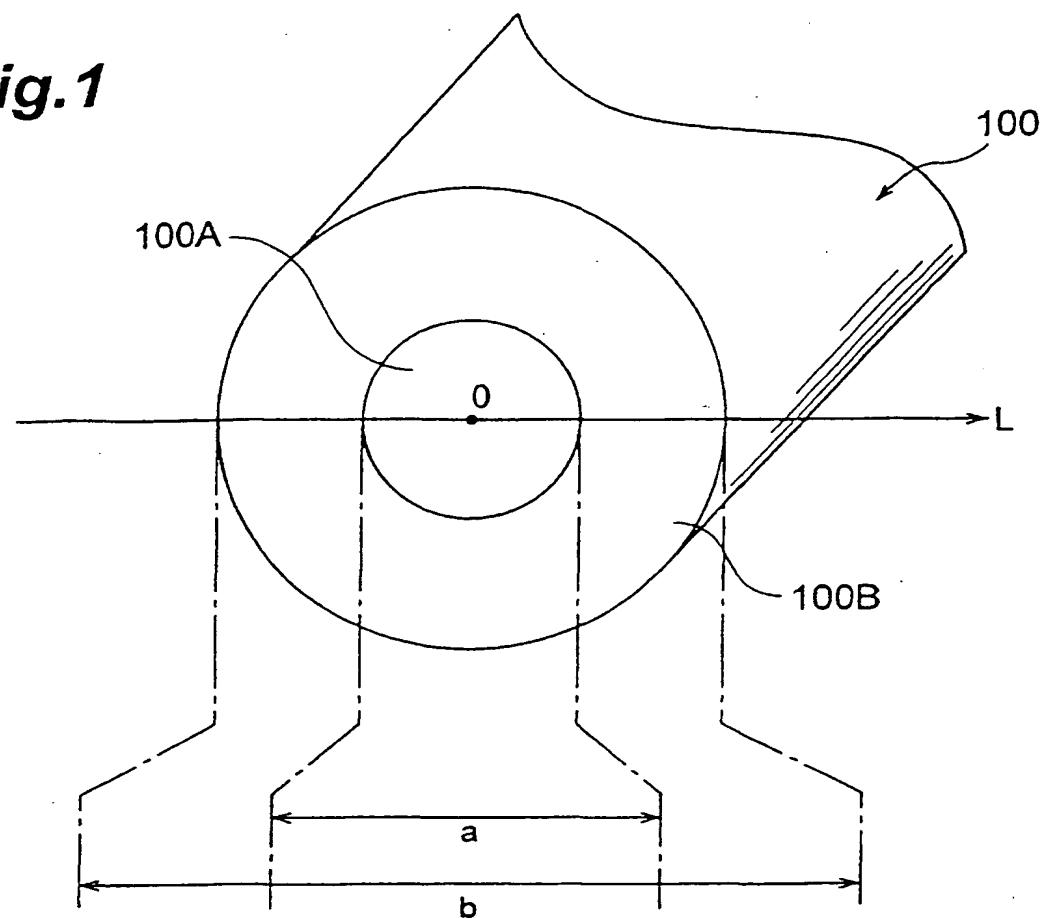
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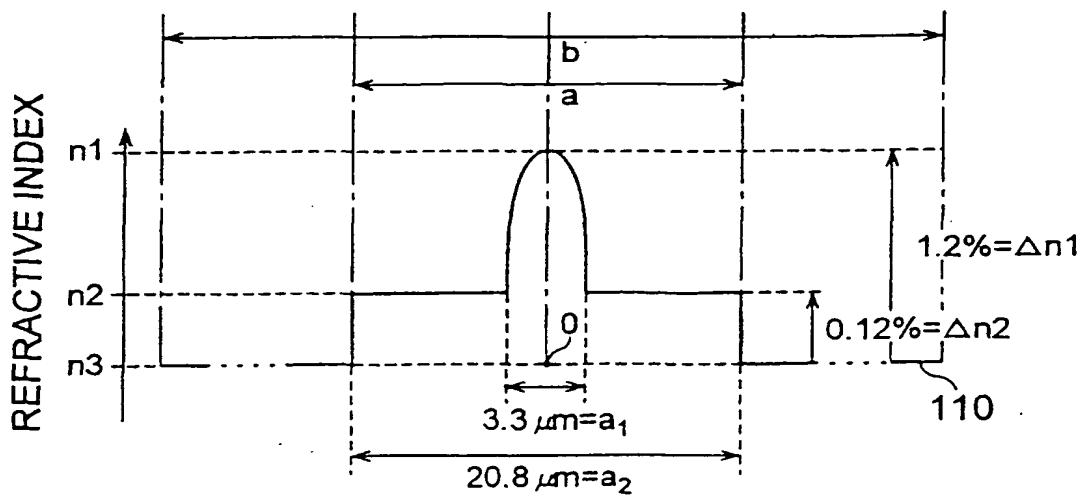
Fig.3

Fig.4

Fig.5A

Fig.5B

Fig.6

REFRACTIVE INDEX

b

a

n1

n2

n3

0

$1.4\% = \triangle n1$

$0.12\% = \triangle n2$

120

$2.8 \, \mu m = a_1$

$23.6 \, \mu m = a_2$

Fig.7

REFRACTIVE INDEX

b

a

n1

n3

n2,n4

0

$1.1\% = \triangle n1$

$0.26\% = \triangle n3$

130

$4.2 \, \mu m = a_1$

$9.9 \, \mu m = a_3$

$14.6 \, \mu m = a_2$

Fig.8

REFRACTIVE INDEX

b

a

n1

n3

n2,n4

0

$1.2\% = \triangle n1$

$0.34\% = \triangle n3$

140

$3.8 \, \mu m = a_1$

$9.7 \, \mu m = a_3$

$13.8 \, \mu m = a_2$
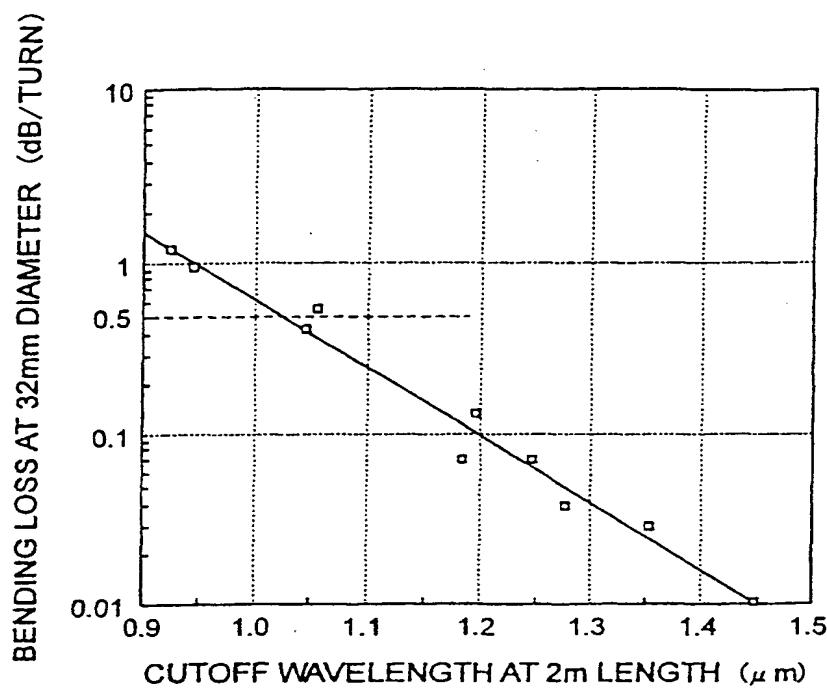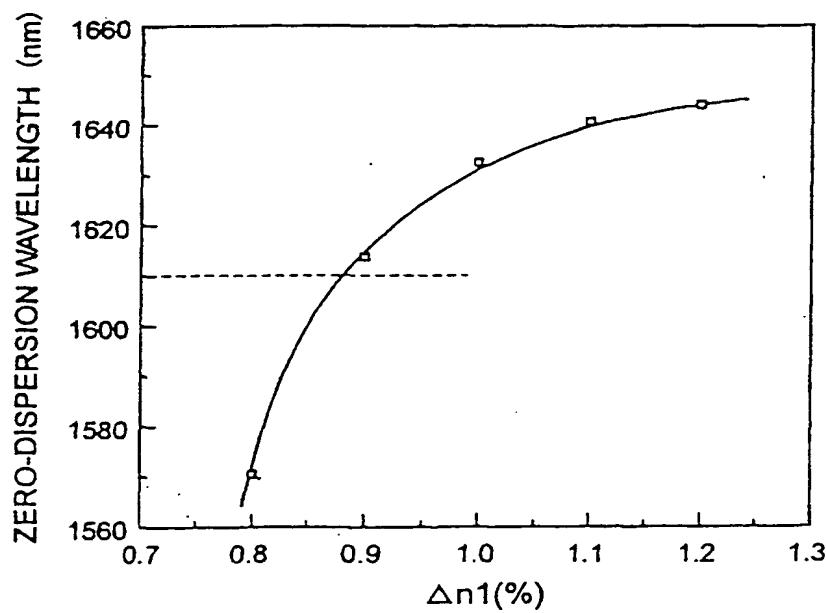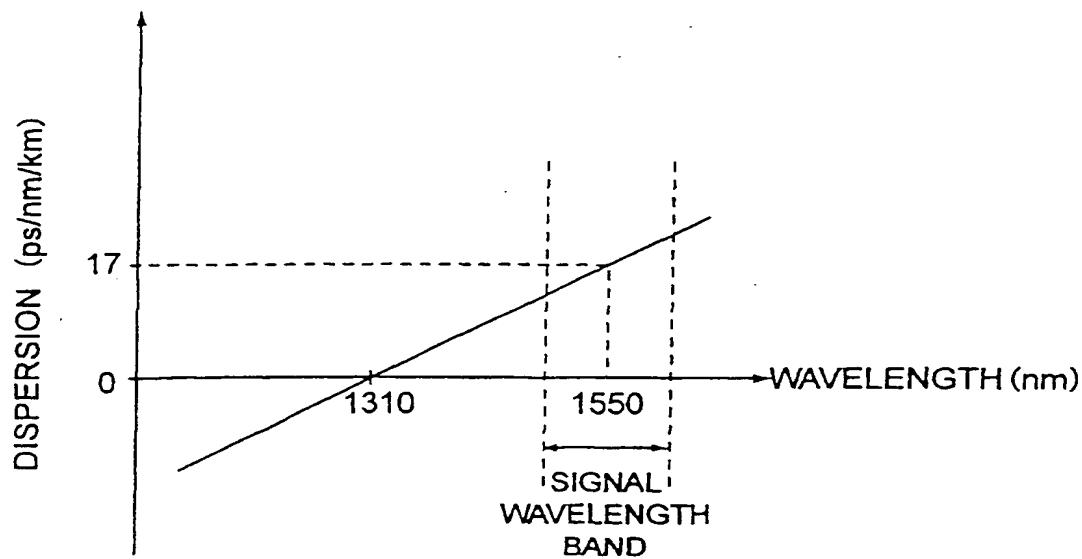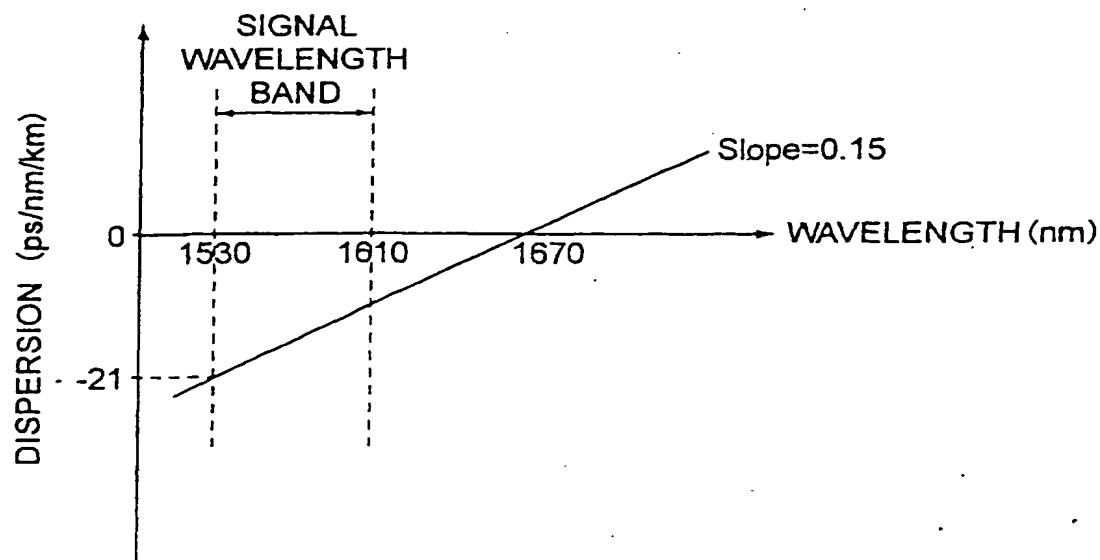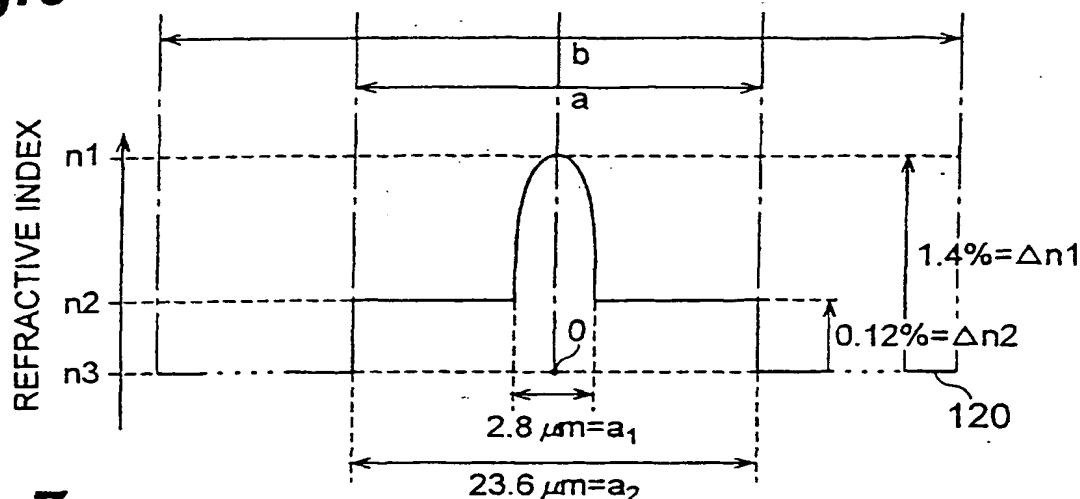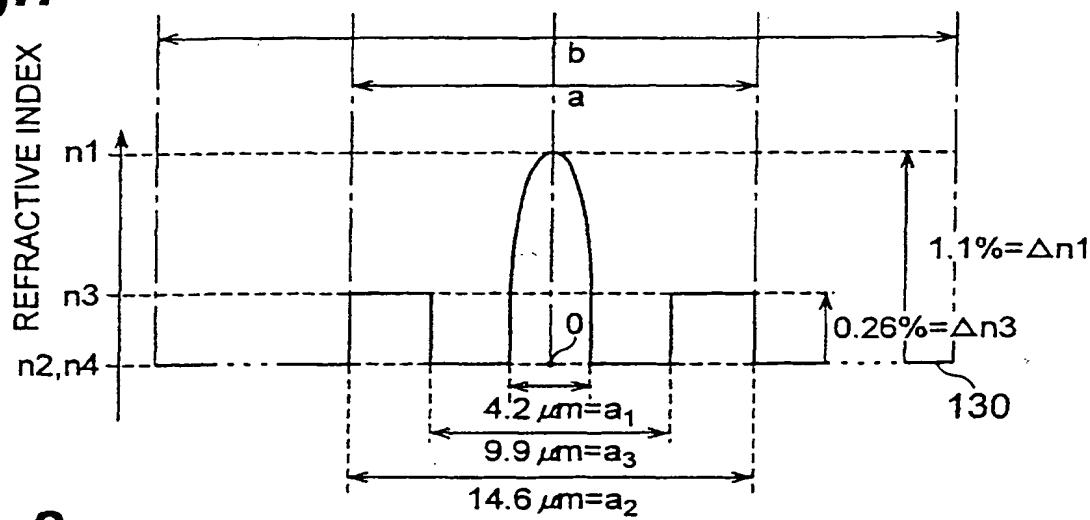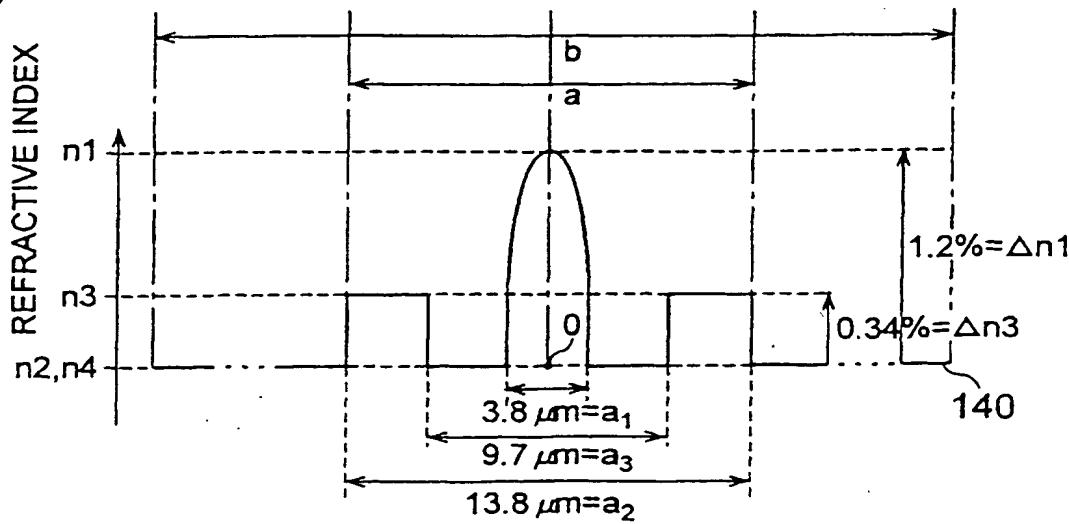
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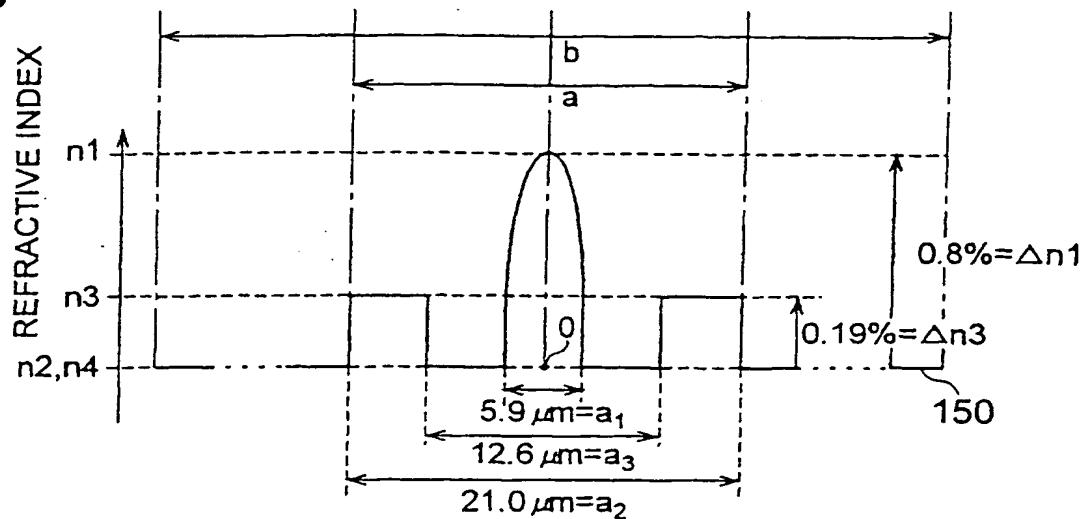
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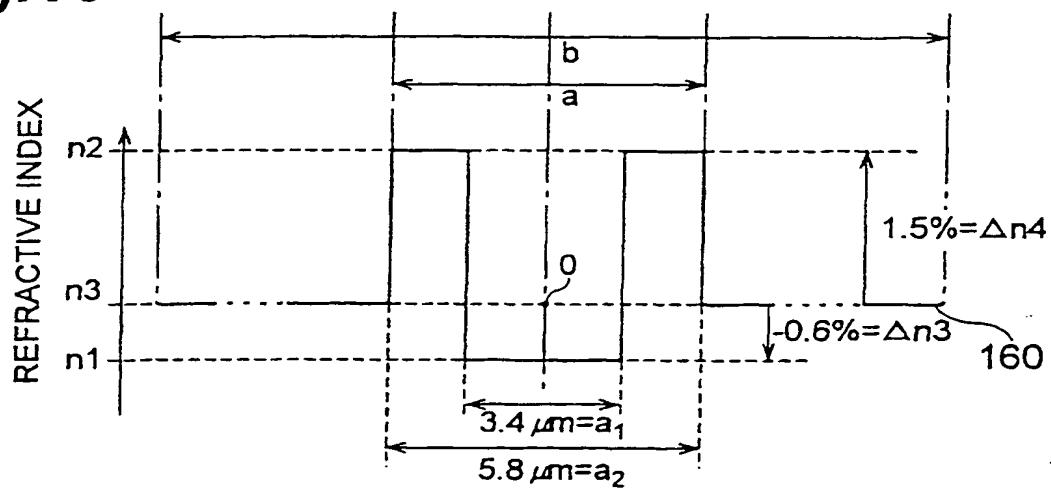
Fig.11
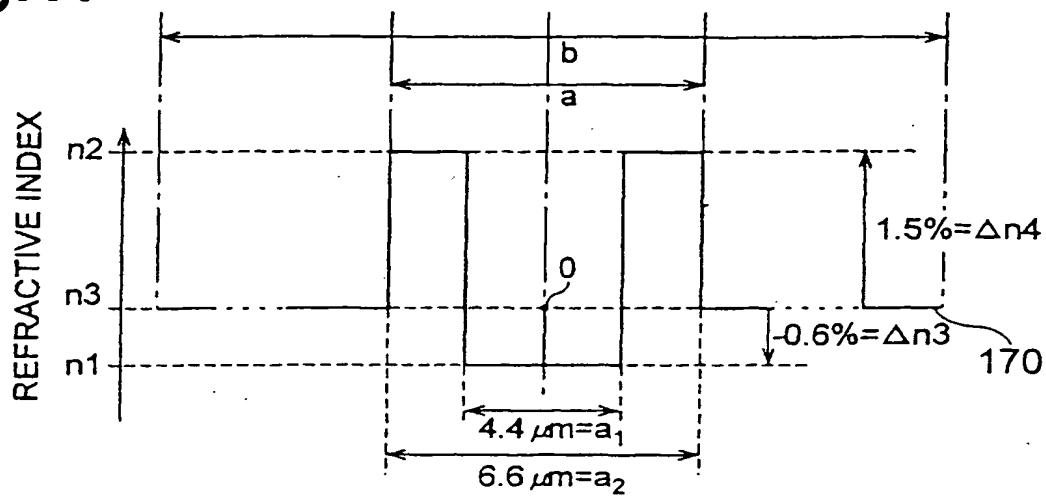
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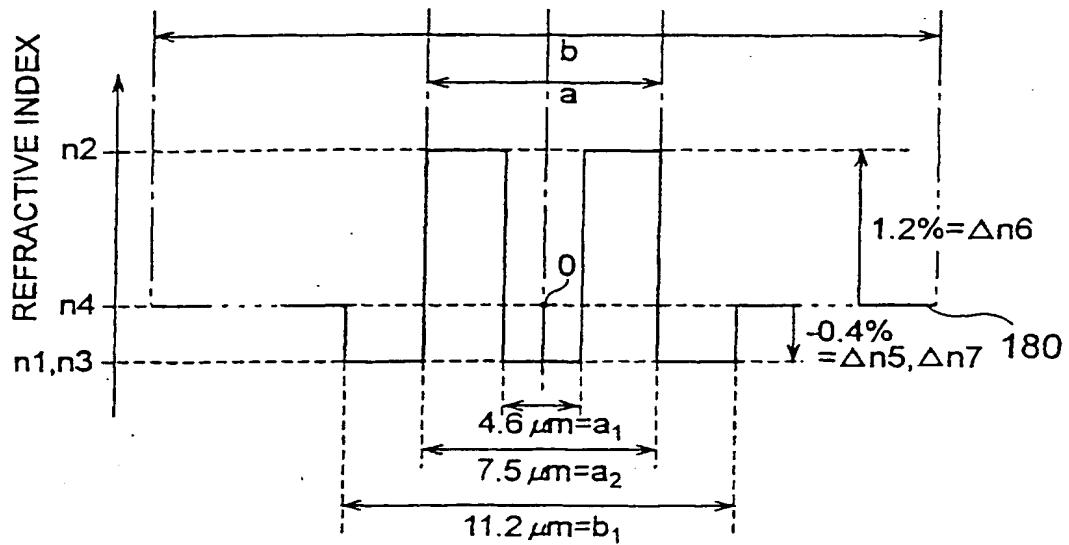
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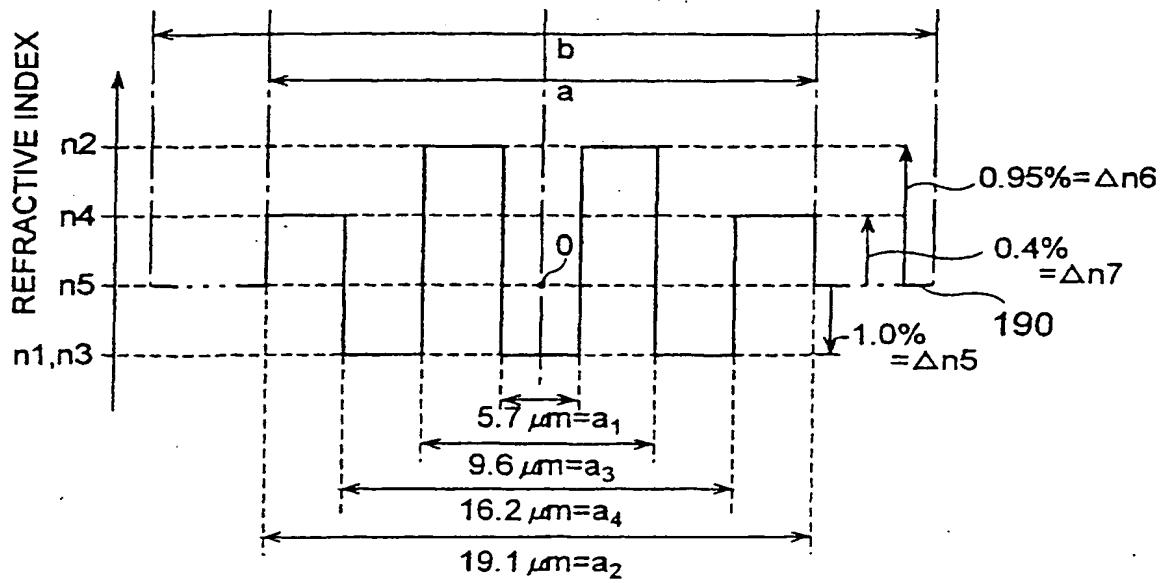
Fig.14

	ZERO-DISPERSION WAVELENGTH (nm)	EFFECTIVE AREA (μm^2)	DISPERSION SLOPE (ps/nm²/km)	CUTOFF WAVELENGTH AT 2m LENGTH (μm)	BENDING LOSS AT 32mm DIAMETER (dB/TURN)
1ST EMBODIMENT	1645	56	0.13	1.46	0.01
2ND EMBODIMENT	1628	71	0.14	1.59	0.12
3RD EMBODIMENT	1654	57	0.15	1.35	0.08
4TH EMBODIMENT	1624	71	0.15	1.45	0.13
5TH EMBODIMENT	1653	56	0.08	1.68	0.03
6TH EMBODIMENT	1634	53	0.09	1.58	5×10^{-10}
7TH EMBODIMENT	1658	73	0.09	1.60	3×10^{-5}
8TH EMBODIMENT	1663	70	0.08	1.52	4×10^{-4}
9TH EMBODIMENT	1625	94	0.07	1.68	4×10^{-4}

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP98/05182

A. CLASSIFICATION OF SUBJECT MATTER
    Int.Cl⁶ G02B6/16

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
    Int.Cl⁶ G02B6/16, G02B6/22

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
    Jitsuyo Shinan Koho   1922-1996   Toroku Jitsuyo Shinan Koho   1994-1999
    Kokai Jitsuyo Shinan Koho   1971-1999   Jitsuyo Shinan Toroku Koho   1996-1999

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
PY	JP, 10-239550, A (Sumitomo Electric Industries,Ltd.), 11 September, 1998 (11. 09. 98), Full text ; Figs. 1 to 13 & EP, 851245, A2 & AU, 9749252, A & AU, 9749253, A & CA, 2225889, A	1-8
PY	JP, 9-318833, A (The Furukawa Electric Co., Ltd.), 12 December, 1997 (12. 12. 97), Full text ; Figs. 1 to 5 & CA, 2201061, A	1-8
Y	JP, 9-505909, A (Alcatel Firbres Optiques), 10 June, 1997 (10. 06. 97), Full text ; Figs. 1 to 4 & EP, 746786, A1 & EP, 749024, A2 & US, 5659649, A & US, 5675688, A & WO, 9607942, A2 & FR, 2724234, A1 & FI, 9603697, A	1-8

[x] Further documents are listed in the continuation of Box C.   [ ] See patent family annex.

*	Special categories of cited documents:	"T"	later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
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"E"	earlier document but published on or after the international filing date	"X"	document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"L"	document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)		
"O"	document referring to an oral disclosure, use, exhibition or other means	"Y"	document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"P"	document published prior to the international filing date but later than the priority date claimed	"&"	document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
10 February, 1999 (10. 02. 99)	23 February, 1999 (23. 02. 99)

Name and mailing address of the ISA/	Authorized officer
Japanese Patent Office	
Facsimile No.	Telephone No.

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INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP98/05182

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JP, 9-211249, A (Sumitomo Electric Industries,Ltd.), 15 August, 1997 (15. 08. 97), Full text ; Figs. 1 to 10 & US, 5732178, A	1-8

Form PCT/ISA/210 (continuation of second sheet) (July 1992)